Rivers and Inlets DRI: Plume, Sediment and Bed Dynamics at the Columbia River Bar

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LONG-TERM GOALS

Our long terms goals are to understand sediment transport processes, the relevant physical forcing processes and the resulting morphologic evolution of river mouths and tidal inlets and shoals. Specific goals include understading the interactions between frontal dynamics, turbulence, sediment transport and bedform evolution under extreme current- and wave-forcing conditions.

OBJECTIVES

1. Quantify the time-varying hydrodynamic structure of the "lift off" zone of the Columbia River as the plume detaches from the seafloor in the vicinity of the bar during varying tidal and outflow conditions.
2. Measure sediment transport magnitude and direction in the vicinity of the "lift-off" region, and relate the transport to turbulence and small and large scale bed topography.
3. Measure small to medium scale (up to 30 m wavelength) bedform topography and migration rates using a tripod-mounted rotary multibeam sidescan sonar.

WORK COMPLETED

Instrumented frames (quadpods) were deployed in two locations at the mouth on May 9 and recovered on June 12. The quadpods were deployed over the mouth bar (Fig. 1), just south of the channel. Pod 1 was heavily instrumented with a pulse-coherent acoustic Doppler profiler (PC-ADP) to provide high-resolution turbulence measurements at 1-cm vertical resolution over the bottom 1.5 m, as well as multi-frequency acoustic backscatter sensors (ABS) to document suspended sediment over the same depth range (Fig 2). This frame also had two sonars for bedform imaging. A side-looking rotary multibeam was mounted at the top of the frame to provide topographic maps of the seafloor within a 10 m radius of the frame at 30 min sampling rates. A rotary sidescan system produced a higher horizontal resolution sidescan image of the seafloor. Both tripods included bottom-mounted, upward-looking ADCPs to provide full water-column velocity profiles, and tripod-mounted T-S-turbidity sensors. Surface moorings with T-S-turbidity sensors provided timeseries of the vertical salinity and suspended sediment structure. The surface buoy at Pod 2 was severed by a fishing vessel part-way through the deployment, and although the buoy and instrument were recovered, no data could be

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recovered from the damaged instrument. Otherwise all of the instruments functioned and provided excellent data coverage of most of the variables (e.g., Fig. 3).

Tow-yo meaurements consisted of rapid vertical profiles using a small-profile, low-drag CTD package (RBR 620) with a 30-lb depressor weight and a high-speed (2.5 m/s) winch. The rapid pay-out of the winch allowed vertical profiling in the extreme shears encountered over the bar during the strong ebbs. The profiles extended from the surface to the bottom for all of the surveys. A 1.2 mHz shipboard ADCP provided continuous velocity data during the surveys. A bottom-actuated Nisken bottle was used during selected transects to provide calibration for the optical backscatter data. Surveys were conducted during two intervals: May 22-27, 2013 and June 7-12, 2013. Surveys included longitudinal and lateral transects across the bar and as far landward as the Astoria-Megler Bridge (Fig. 1).

RESULTS

Although a number of studies have been conducted in the Columbia estuary and plume, no study until now has successfully resolved the hydrodynamic conditions across the bar during peak flow conditions—spring-tide ebbs during peak river outflow. The tripods provided continuous measurements of the extreme flow conditions across the bar, and the salinity variation during the deployment verified that the pods were squarely situated within the frontal zone (Fig. 3). A survey in the early morning of May 26, 2013, successfully resolved the formation of the "lift-off" front during extreme spring-tide conditions (Fig. 4), during which the salinity front was pushed seaward of the tips of the jetties (km 1). The suspended sediment data (lower panel, Fig. 4) indicate significant resuspension landward of the front and trapping within the front. However, the highest sediment concentrations were observed during the subsequent flood tide, due to intense bottom stress associated with the landward-propagating salt wedge (Fig. 5). These results indicate the importance of the interaction between the density structure (due to salinity variation) and velocity in determining the stress distribution and the resulting sediment transport.

The tripod measurements provide a more continuous assessment of the sediment transport processes than the surveys, although without resolving the spatial variability. Preliminary examination of the suspended sediment fluxes at Pod 1 suggests that the net near-bottom sediment transport is slightly landward during neap tides and seaward during the strong spring tides. The water-column average sediment transport appears to be persistently seaward, due the strong net outflow of fine sediment. The sediment flux is the result of a combination of bedload flux, as measured by ebb-dominated bedform migration and suspended load as measured by Acoustic backscatter and Doppler profilers. Similar to bedforms observed in the tidally dominated channel of New River Inlet the bedforms reverse migration direction in each half-tidal cycle. The spatial scales of the bedforms are slightly larger than those measured at New River with wavelengths of 7 to 9 m and heights of 70 cm (Fig 6) .

Another preliminary result is the indication of very low values of the gradient Richardson number (Ri) during strong ebb conditions. Other estuarine environments typically show values of Ri close to 0.25 during strong forcing conditions, but the Columbia River data indicate values as low as 0.1 for extended periods, even while stratification is being maintained. The persistently low values of Ri during stratified condition indicates intense buoyancy flux, resulting from the combination of high stress (due to very strong tidal velocities) and large horizontal buoyancy flux (due to high river outflow). We presently pursuing calculations of bottom stress from our pulse coherent Doppler sonar (Fig 7) and acoustic velocimeter data. This dynamical regime only occurs in most estuarine systems during rare, extreme flood events, but in the Columbia River this condition appears to occur regularly,

due to the combination of strong tidal forcing and annual peak river flow. The implications of this intense mixing regime on the estuarine dynamics and sediment transport regime are subjects of ongoing analysis.

IMPACT/APPLICATIONS

This study has demonstrated that high-quality measurements of hydrodynamic and sediment-transport variables can be obtained even in extreme wave and current conditions. The analysis will yield important insights about the interaction of currents, waves and estuarine salinity fronts as they influence sediment transport, bedform dynamics, and morphological evolution of river mouths and inlets.

RELATED PROJECTS

This project is also closely related to several other proposed ONR efforts including an OASIS project with John Trowbridge to measure wave boundary layer stresses in support of optical measurments of particle dynamics (Environemental Optics), and integrating the pcADPs on Geyer's MAST (Physical Oceanography). The DURIP funding was also used to develop equipment for those projects.

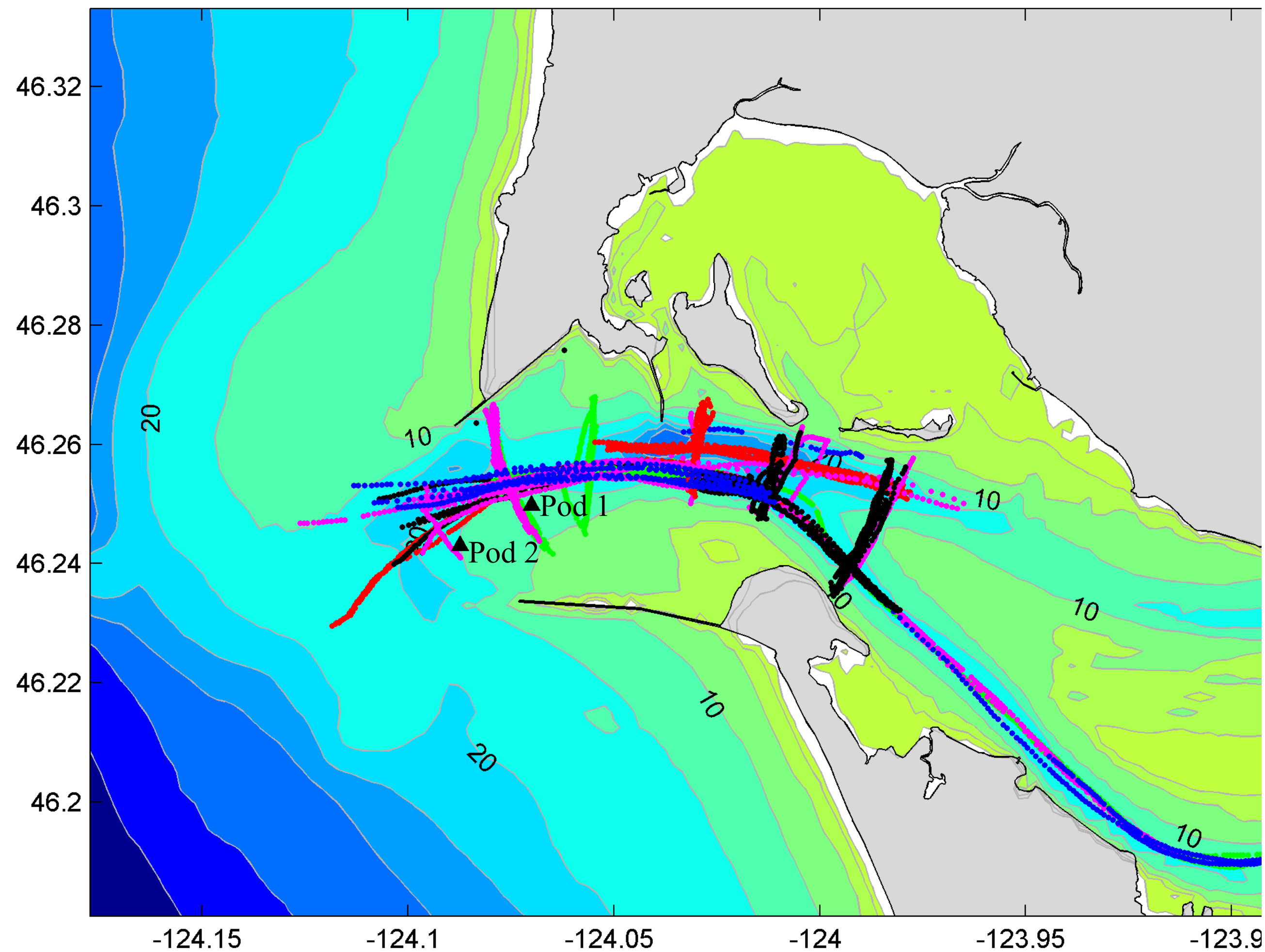

Figure 1. Locations of tripods (triangles) and tow-yo survey lines (dots indicating individual profiles during the May-June 2013 deployment. Occasional gaps are due to extreme wave and/or current conditions.

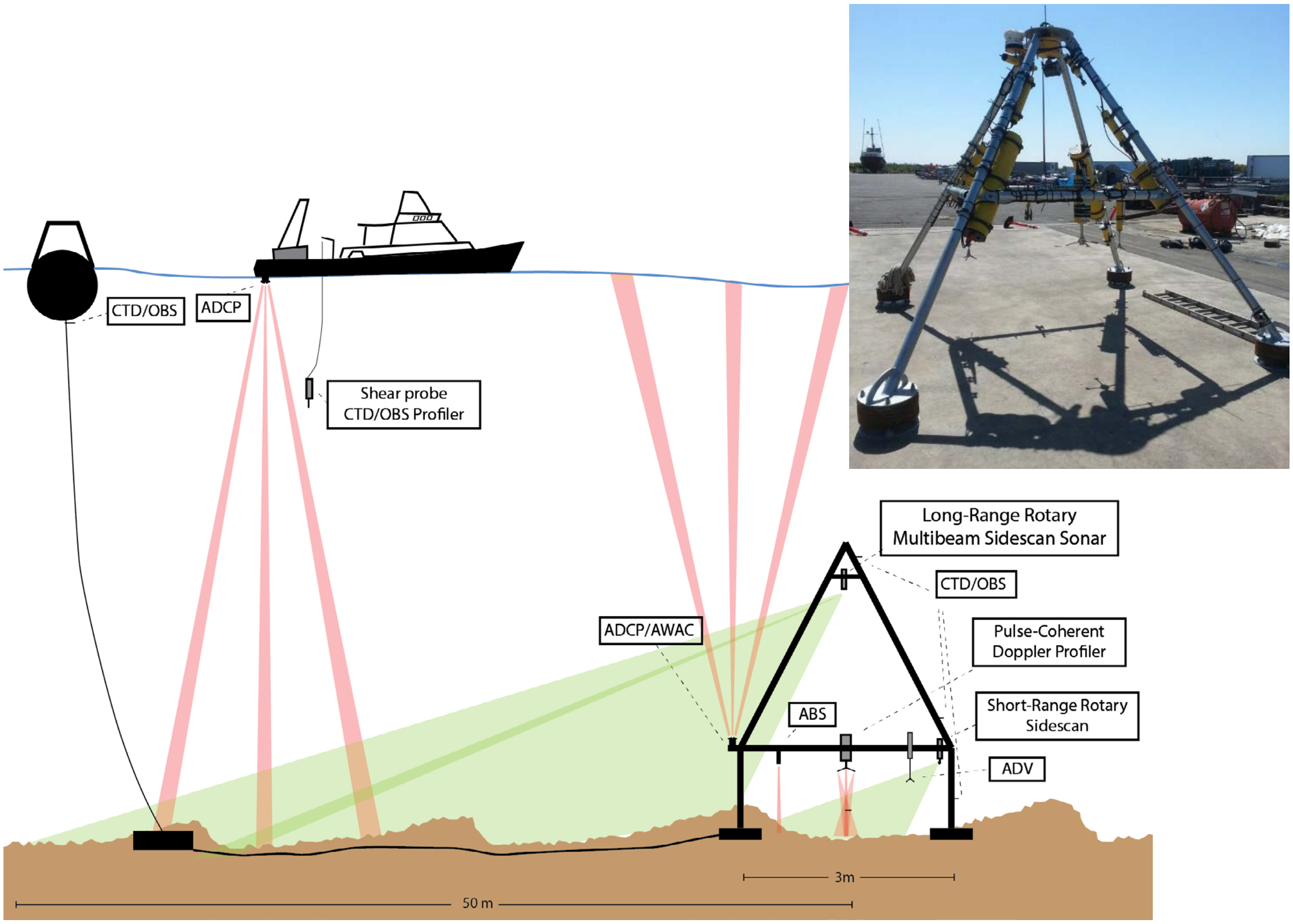

Figure 2. Schematic of the deployment configuration showing the shipboard survey operations, moorings and instrumented frames with a photograph of the heavily instrumented frame inset.

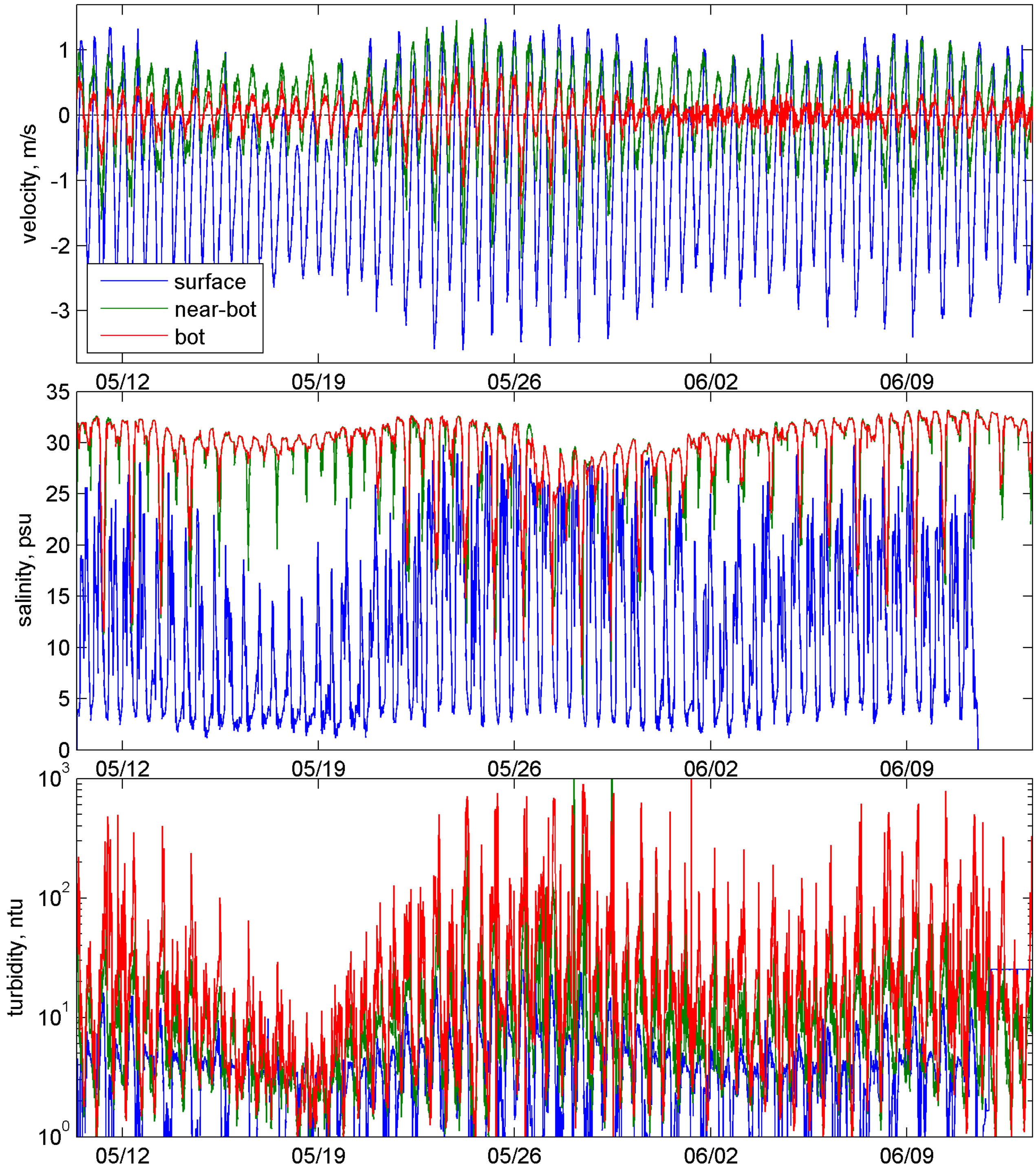

Figure 3. Along-channel velocity, salinity and turbidity from Pod 1 (location indicated in Fig. 1). Note extreme near-surface current velocities (>3 m/s). The large variation of surface and bottom salinity is due to the advection of the front past the tripod location. Turbidity peaked during spring tides.

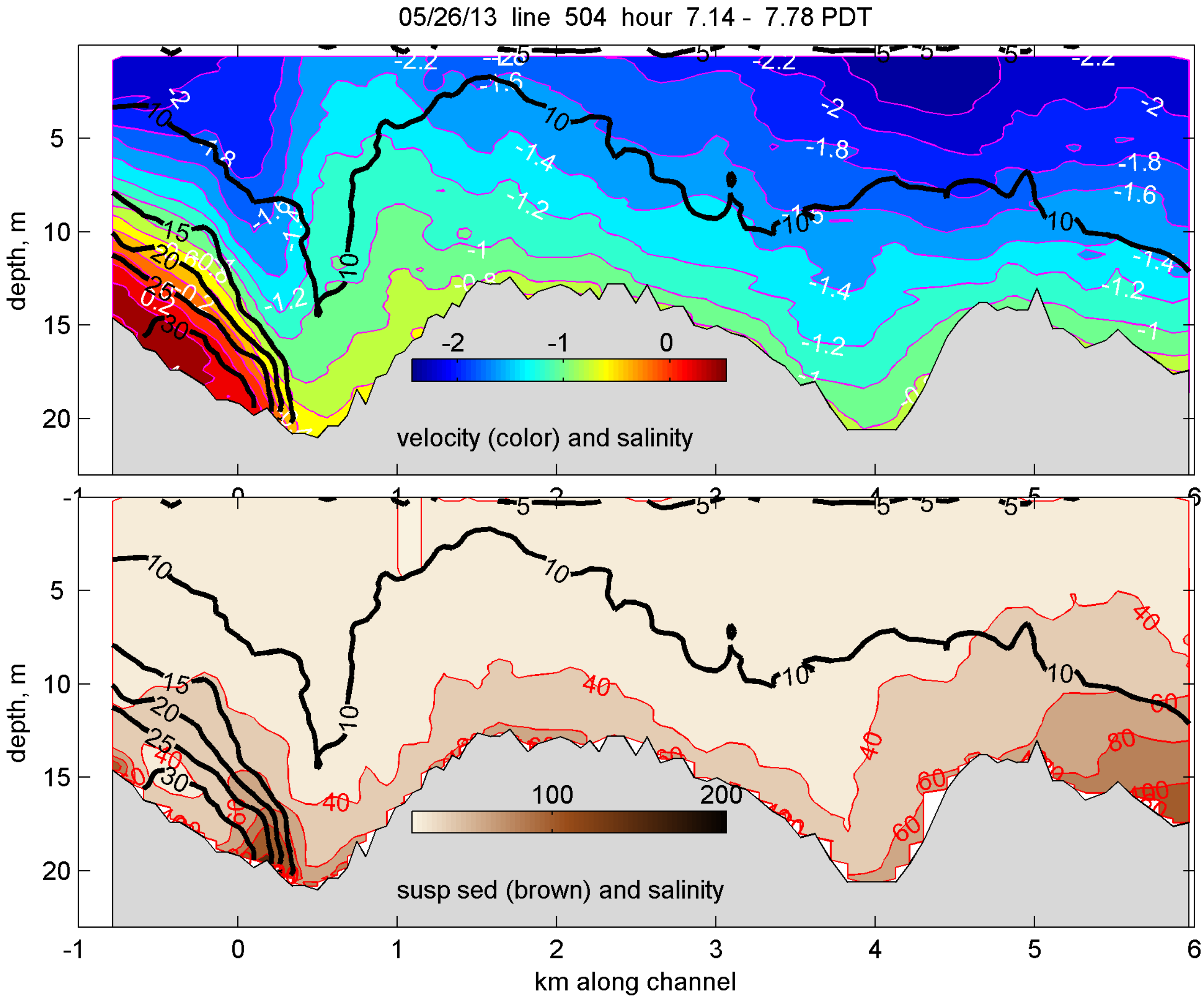

Figure 4. Velocity, salinity and suspended sediment distributions at the end of the strong ebb during extreme spring-tide conditions. Salinity contours are shown in black contours in both panels. Near-surface velocities peaked at 3.5 m/s earlier in the ebb but declined to 2.5 m/s at this time. The salinity front formed close to km 0, just seaward of the tips of the jetties.

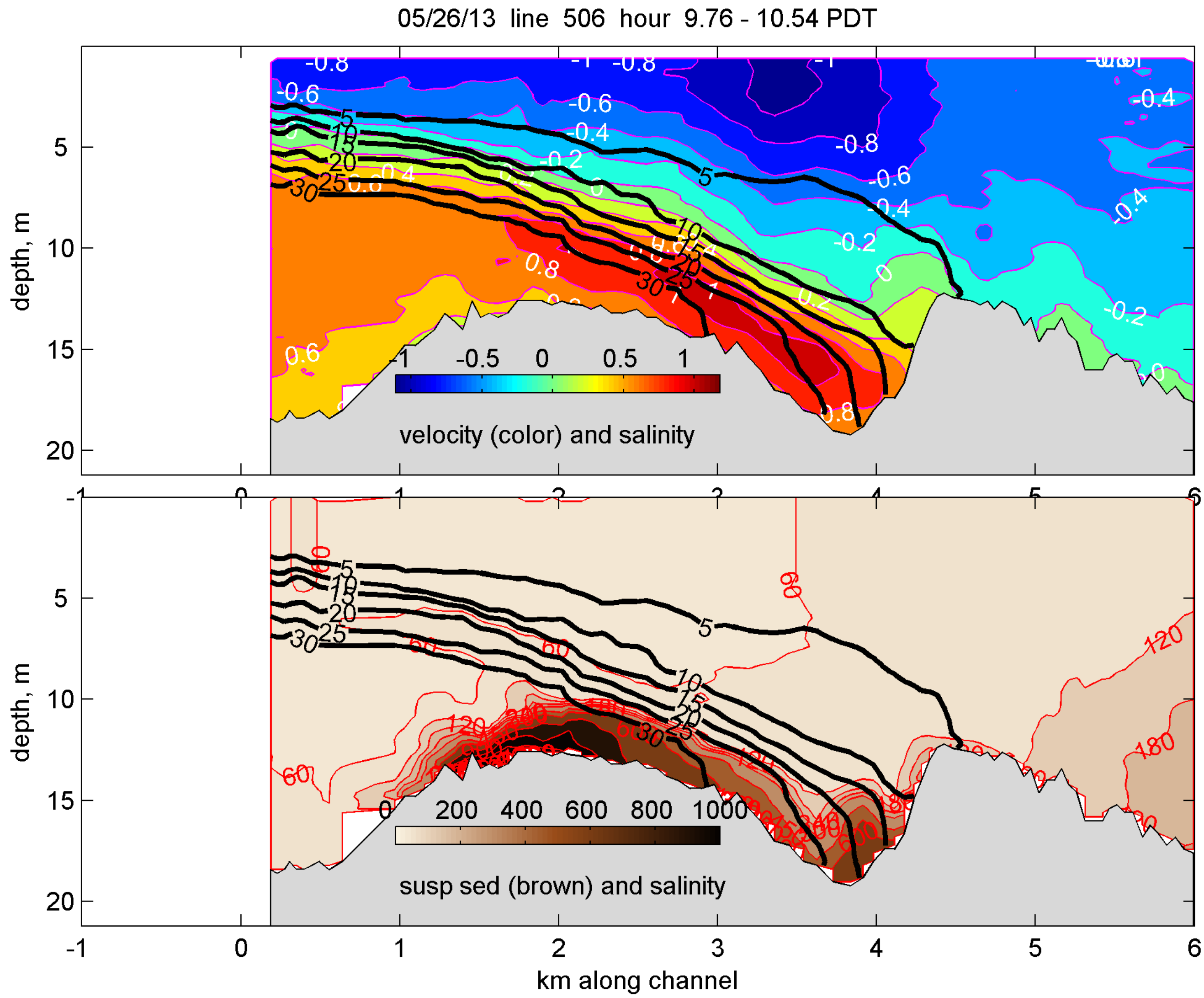

Figure 5. Velocity, salinity and suspended sediment distributions during early flood following the front-formation shown in Fig. 3. Near-bottom flood currents exceed 1 m/s over the bar at km, 2 resulting in intense sediment resuspension (concentrations exceeding 1000 mg/l.)

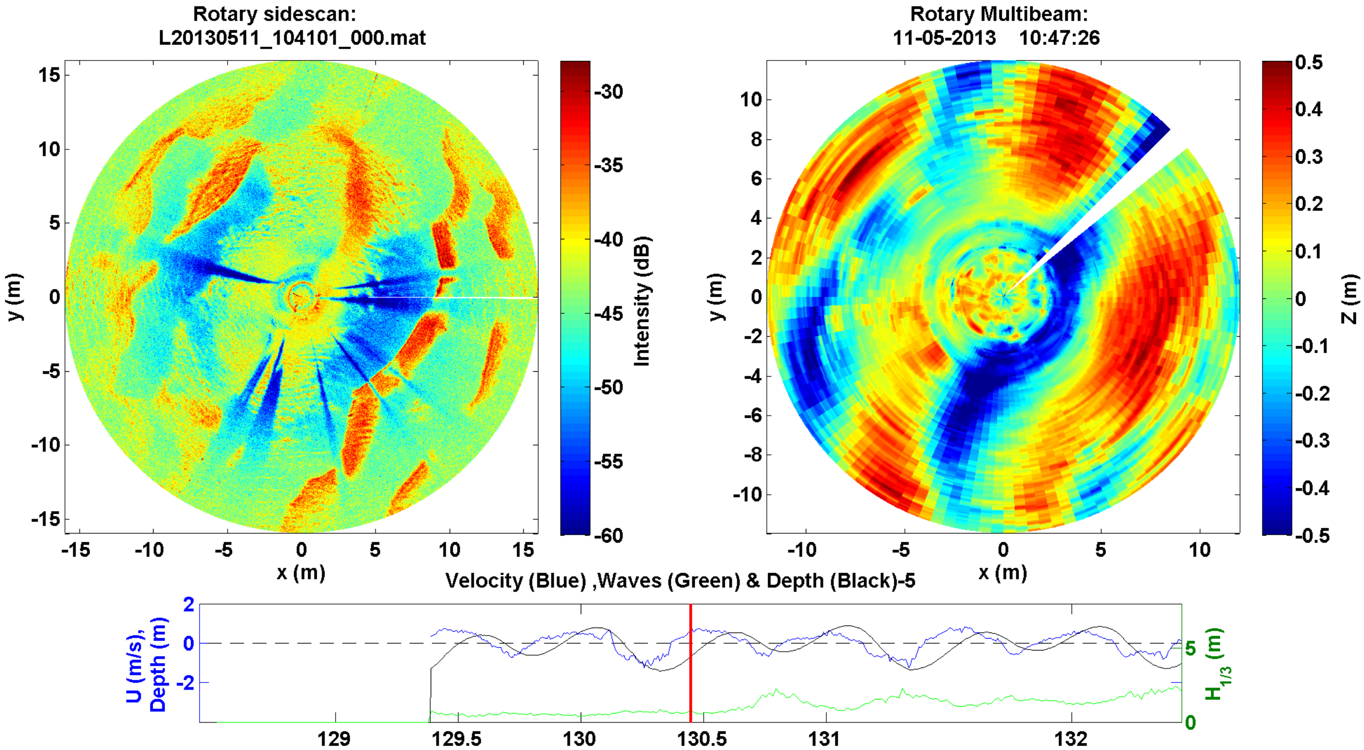

Figure 6. Bedforms as imaged by a rotary sidescan sonar system (upper left) and side-looking multibeam sonar system (upper right). The multibeam produces a slightly lower horizontal resolution topographic map with bedform heights of 70 cm. The sidescan produces an detailed image with acoustic intensity proportional slope of the bedforms. Both show wavelengths of 7 to 9 m. The bottom panel shows wave height, depth and along -channel current velocity.

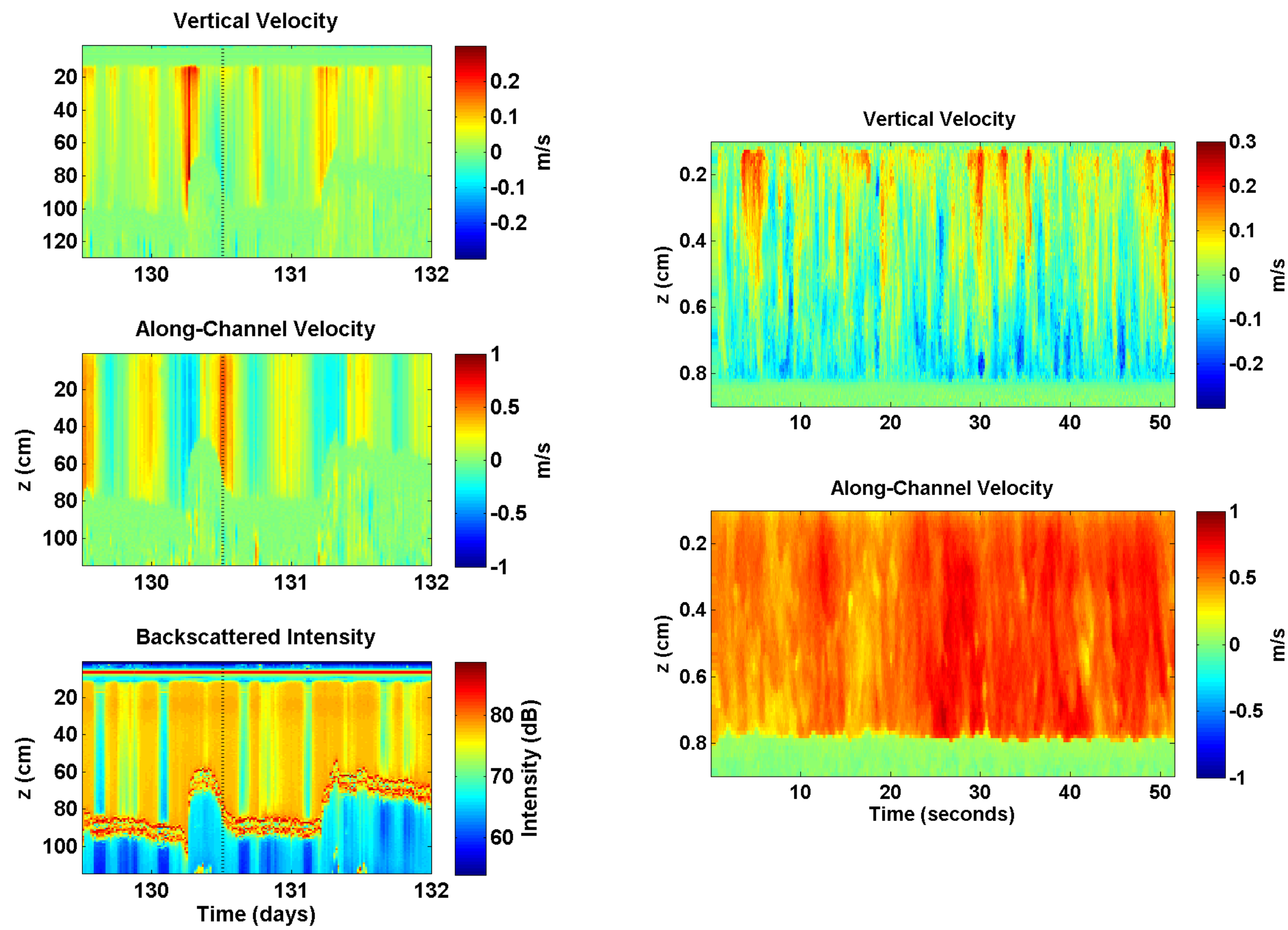

Figure 7. Pulse-Coherent Doppler Velocity Measurements. Left panels show burst averaged data as a dune migrates under the sensor. Large upward vertical velocities are present before the passage of the dune and downward velocities are visible afterward. Right panels show 10 Hz sampling rate turbulent velocities with fluctuations of 20 to 30 cm/s in both horizontal and vertical velocities.